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THE ENFIELD MARINE AMPHIBIOUS FREIGHT HOVERCRAFT

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THE ENFIELD MARINE AMPHIBIOUS FREIGHT HOVERCRAFT

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1. INTRODUCTION Enfield Marine, part of the Enfield group of companies, was established in 1968 to construct high speed marine craft and considerable success has been achieved in the power boat racing world with such boats as 'Miss Enfield' I and II.

To enter the hovercraft industry was a logical development of the company's activities but before this step was taken at the end of 1969, an intensive study of existing craft, their capabilities, costs and markets was carried out. This study indicated that the two extremes of the hovercraft speed spectrum were fairly well developed.

On the one hand there exists the high speed, light weight craft, using the refined techniques of the aerospace industry coupled with intensive research and development necessary to an emerging industry. This approach resulted in an expensive vehicle applicable only to the high density passenger routes where the revenue justified the initial cost. It augurs well for the future of hovercraft that their operations have survived in competition with displacement vessels, their reliability has generated increases in local traffic.

At low speed the hovercraft principle has been used to overcome the inconvenience of the wheel, to spread a load more evenly over poor load bearing surfaces; as exemplified in the 'off the road' transporters of Air Cushion Equipment Limited; to increase the load bearing capability of conventional surfaces, as in the C.E.G.B. heavy load transporters, and to move very large pieces of equipment over relatively short distances without incurring problems of jacking and loading. In these endeavours speed would appear to be a low priority requirement, if not an embarrassment. Custom built equipment has been designed for specific tasks, but collectively, clearly demonstrating the capabilities of the air cushion principle.

There exists between these two extremes a requirement for a moderate speed and relatively cheap workhorse, a vehicle not limited by wheels or hull, and capable of a wide range of duties. This belief is encouraged by the instances which have occurred where amphibious fast ferry hovercraft have been modified for use in exploration, survey, military support operations and heavy load carrying. While these have been for the most part successful it is apparent that the modification of a technically advanced, high cost craft for this type of role is not the ideal method of production, nor can such an approach be profitable.

On these considerations the decision was made to enter the hovercraft business.

In defining the Enfield project aim, it was encouraging to consider that we would not be in direct competition with other manufacturers. With limited staff and non-existent research facilities we could not expect to survive against the aerospace industry in the production of fast ferry type of hovercraft.

2.BASIC PHILOSOPHY The aim of the Enfield projects therefore is to produce 'general purpose' hovercraft catering for a multiplicity of roles but specifically aimed at the market which exists in development areas of the world. Significant economies will result from the use of hovercraft in major civil engineering projects for by this means it is no longer necessary to budget for temporary roads, railways and quays. The implication of such operations is of course that the amphibious capability of the hovercraft is absolutely essential and is its most important single feature. A freight and general purpose hovercraft may justify its cost by carrying out tasks which have been impossible or totally uneconomic by other forms of transport. The amphibious quality provides the means to extend the boundaries of development, surmount physical barriers, and to exploit the natural resources of developing countries.

These operational uses can be said to warrant the development of a hovercraft but a broader market is required to justify establishing a production line of a new type of vehicle. A special purpose vehicle is unlikely to operate more than 2000 hours per year and a useful life under arduous conditions will not exceed ten years. The initial cost amortised over this order of useful life becomes a significant part of the operating costs. To generate the required market it is essential that the prime costs of the vehicle are low enough to permit profitable operation on such an order of utilisation, indeed new operational uses will be discovered once the vehicle's profitability is proven.

To further extend the potential market there must be considerable flexibility in the payload/speed relationship. At the top end of the scale high speed implies design complexity and high cost engineering techniques both to reduce the basic weight to a minimum and to provide a satisfactory payload at high speed. These techniques are not compatible with low first costs and it is considered that provided the vehicle can be operated in wind and wave conditions consistent with its range and size, high speed is not a prime requirement.

It is an inherent characteristic of hovercraft that impressive increases in payload can be tolerated at the expense of speed. Thus a craft designed to operate in the 30 to 40 knot speed range carrying a payload of the order of 30 per cent of the 'all up' weight can reasonably be expected to carry at least three times this payload at much reduced speed provided that this flexibility is catered for in the initial design.

This feature, together with the wide variety of loads such a vehicle would be expected to carry, argues against any closed form of freight compartment and it is considered that the basic form must be a load carrying platform which can be adapted easily for a multiplicity of roles by the addition of simple superstructures.

Other features which have a direct effect on structural and other design facets are inherent in the basic operational role. Use in underdeveloped areas implies rough conditions, a minimum of technical and engineering support and, in many cases, extremes of environmental conditions. These in turn point to a rugged, simple vehicle with, as far as practicable, minimal maintenance requirements, to be carried out without special tools or equipment and without highly trained personnel. Wide variation in environmental temperature and surface conditions dictate the selection of vehicle equipment and components.

Again, because of its basic role, and to increase utilisation and therefore profitability it must be possible to transport the vehicle to its operating area quickly, preferably as air cargo. Such **portability,** however, does impose serious structural problems and weight penalties.

Finally there are problems facing the hovercraft engineer in producing a vehicle which has no positive contact with the surface over which it operates. Manoeuverability, control and stability are three formidable problems, particularly when, as noted above, the accent is on simplicity. A further area of difficulty arises from the use of air propulsion which the amphibious nature of the craft dictates. Initially, because of the novelty of the vehicle the noise produced by propeller driven hovercraft was tolerated but in a society which is becoming increasingly conscious of environmental noise, the hovercraft manufacturer is continually being urged to reduce the nuisance level of his product. In designing for a wide and varied market this feature requires intensive consideration.

Summarising, the targets and design aims based on a general survey of existing vehicles, potential markets, and the basic qualities of the hovercraft, lead to a craft which:-

1. Can be adapted to a wide range of freight and general purpose duties.
2. Is amphibious
3. Has a moderate first cost and low maintenance and operating cost, implying simple and rugged construction.
4. Will operate in extremes of environmental conditions.
5. Is portable.
6. Has a high standard of control and manoeuverability.
7. Has a minimum nuisance level.

3.DEVELOPMENT PROGRAMME Having established the basic parameters, the Enfield design studies crystallised into the E.M.1. project. A comprehensive project design and development programme, consisting of three distinct phases, was drawn up and initiated.

Phase 1 Project calculations defining the major parameters were followed by the construction of a 1/10 linear scale dynamic model. Model tests were carried out at the N.P.L. tank at Hythe to determine the static pitch and roll stiffness of the cushion system and the drag of the hovercraft at various weights and in a range of sea state conditions. The skirt system behaviour was closely observed and a number of modifications introduced to improve the cushion characteristics. From the results of these tests revisions were made to the project design.

Phase 2 The next stage of the development programme required the design and manufacture of a nominally half-scale model of the E.M.1. This vehicle, designated E.M.2., was planned to serve several major purposes.

During manufacture it would:-

1. Provide the workshops with experience of the form of construction defined for the eventual project.
2. Enable the Enfield organisation to become orientated to the requirements of hovercraft manufacture.
3. Familiarise the design, manufacturing, quality control and administrative groups with each others functions and responsibilities.

Once afloat the manned model would provide data on the lift, propulsion, and anciliary systems which would prove invaluable in the detail design of the E.M.1.

Since the E.M.2. project was proposed such interest has been shown in it as a working vehicle in its own right that we intend to put it into production. The first three craft are currently under construction in our Ryde factory.

Phase 3 The third phase will involve the detail design and production of the E.M.1. Present estimates indicate that the prototype E.M.1. will be completed in 1973.

4 INTERPRETATION With the design aims and requirements identified a description of the E.M.2. detail design will serve to illustrate the Enfield approach to the practical interpretation of the requirements.

Figs. (3) and (1) show respectively the general arrangement of the E.M.2. and an artist's impression which clearly depicts the amphibious ability of the craft as it transports civil engineering equipment and stores from ship to shore.

4.1. Model Work Project calculations of performance are illustrated in Fig. (6). These preliminary estimates were qualified by the dynamic model tests at Hythe and once some initial problems were cured encouraging results were obtained.

Following the aim to produce a craft with a flexible payload/speed capability the tests at normal 'all up' weight were followed by runs with the model weight increased to represent the 100% overload case. These tests also were encouraging and satisfactory speeds were obtained both overland and in calm sea conditions. It is interesting to note that even with a payload increase to 240% of the normal, the cushion pressure is only increased by 35%.

As well as performance great care was taken to examine the cushion stiffness characteristics with particular reference to the need for some form of CG or CP control having in mind the nature of work for which the craft was designed. These tests showed that at the speeds required, the craft will be insensitive to reasonable variations of CG and trim and unless trials prove otherwise, it is not intended to include any such control in the craft. A skirt shift system has been designed and will be incorporated into the prototype E.M.2. if the inherent stability of the cushion system is not completely satisfactory.

4.2. Skirts The skirt is the most important part of any hovercraft and particularly is this so in the amphibious vehicle. The cushion system selected for the Enfield projects is basically the H.D.L. loop and segment arrangement. As noted above the model tests showed this form to have both reasonable drag characteristics and adequate stability.

Skirt wear has been a significant problem with all hovercraft, the amphibious machine suffering more than others.

To produce a skirt system for operation over all surfaces and in all environmental conditions is expecting the impossible. It is highly probable that skirt systems and the materials from which they are made will be selected for specific operational duties and climatic conditions. For instance, natural rubbers retain their flexibility at low temperatures and are highly resistant to contaminants such as oil. The properties of butyl based materials, however, are liable to change in reduced temperatures but they have superior abrasion resistance. The presence of contaminants will accelerate delamination between the butyl material and the reinforcing fabric.

Material evaluations and developments are a continual pursuit of the Avon Rubber Co. who have been selected to manufacture the E.M.2. skirt. The choice of materials is also affected by maintenance and economic considerations. Because of its role the E.M.2. is designed so that skirt components can be replaced easily without lifting the craft. It may prove more economic to use a relatively low grade and cheap material and replace the components more frequently, rather than invest in the development of long life components. Only operational experience can prove this. A selection of materials is installed in the prototype skirt for evaluation.

Avon Rubber Co. involvement in the Enfield projects illustrates a basic principle of our policy. With our very small design and development staff it is not possible to carry out the detail design of all the many components of a hovercraft. We therefore rely very largely on the specialist manufacturers working to detailed specifications to produce a major proportion of the craft components. This not only has the advantage of employing specialist knowledge but a relatively low overhead cost can be achieved since the design is supported by established products. The sub-contracting policy also means that the product can be supported in the field if necessary by specialist service engineers.

4.3. Structure With its world wide role in mind the structural concept of the E.M.2. has been kept simple and robust using commercially available materials and, for the most part, the traditional skin and stringer arrangements. With its background and experience in the construction of weight sensitive boats, Enfield Marine has directed the available marine skills to the manufacture of hovercraft with few problems of adjustment to the new techniques. The low overheads of the marine industry has a predominant effect on the first costs of the E.M.2.

The requirements of simplicity, portability and high load capacity have resulted in a basic three part structure, a central load carrying platform and two side structures carrying machinery and services. The requirements of portability are of course expensive both in terms of weight and cost and the E.M.2. has been designed on the assumption that the craft is unlikely to require dismantling more than twice a year. This will involve not only breaking the craft into the three basic structures but also the removal of the cabin and the propulsion units. To dismantle the craft is not an easy operation, to simplify this exercise would impose a severe structural penalty and one which will not be attempted, at least on early production craft. The photograph, Fig. (2), taken during the building of the E.M.2. prototype shows the form of construction in the area of the transport joint and illustrates the simplicity of the structure.

Large unobstructed freight decks are features of E.M.1. and E.M.2. designs with the easiest possible access both for overhead loading and from the roll on/roll off point of view.

E.M.1. has the roll-through access to its freight deck which is 54 ft. long by 16 ft. wide, but the physical size of E.M.2. did not permit a full width ramp to be used at the bow, this facility has been provided at the stern. In order to keep the loading height to a minimum and to permit high density loads the deck is constructed of light alloy honeycomb panels. This deck has a clear area of 35 ft. by 8.5 ft. and for normal operation will carry payloads up to $3\frac{1}{2}$ tons. Production E.M.2's will be capable of carrying an overload payload up to $8\frac{1}{2}$ tons. Overall loading densities up to 150 lb/ft. and local wheel loadings of 2000 lb. at pressures of 50 lb/in^2 are permissable. The ability to operate with heavy loads, although at reduced speed, has been a design condition applied to the E.M.2. structure. Developed versions of the engine and propulsion systems will admit of further increases in the vehicle's payload capability.

For normal freight work a flexible waterproof cover would be used to protect payloads where necessary. For certain operations, surveying or exploration for example, additional personnel may be accommodated in a simple portable cabin secured to the freight deck. Many variations are possible for civil or military applications, too numerous to include in this paper. The clear deck arrangement, however, is analogous to the commercial road vehicle, a basic chassis-cabin arrangement which can be adapted to innumerable specific roles.

4.4. Machinery and Control As in the case of the structure the accent on all the machinery and systems design has been on rugged simplicity, and ease of maintenance. Control, electrical, hydraulic and fuel systems are of basic design avoiding the need for "mysterious black boxes". As noted, the policy of using expert manufacturers and standard components has been used wherever possible, not only to provide the best design experience available at reasonable cost but also to give expert back-up in the field when necessary. As far as practicable all components and systems have been selected with an eye to their ability to function satisfactorily in extreme temperature conditions. However, it may be found advisable to carry out specific modifications to fit the craft for particular operations.

In common with the policy of design for a wide range of duties the E.M.2. will be powered by either lightweight air cooled diesels or gas turbines, the choice will depend upon the utilisation of the craft and, of course, the requirements of the operator. Deutz 12 cylinder turbo-blown air cooled diesel engines or two Waukesha T400 industrial gas turbine engines are available. The gas turbine installation permits a greater payload to be carried but a comparative study of the economics shows insignificant difference in the costs per ton/knot in the two arrangements; the economic study based on an endurance of $3\frac{1}{2}$ hours. Transmission components are such that will require no specialised knowledge for maintenance and servicing, wherever possible standard, commercially available parts have been employed. In the diesel engined E.M.2., power for the lift system is taken from the front of the engine via a standard marine reduction gearbox. The lift fans are modified industrial components made in light alloy and incorporating a hub of Enfield design. Each engine drives two lift fans which, by their location, feed air to the cushion system at the forward part of the craft. This arrangement has been selected to ensure rapid replenishment of cushion air after the craft has negotiated an obstacle, thus avoiding violent pitching motions. Air is bled from the lift fan volutes to cool the diesel engine or, in the gas turbine craft, to provide the engine with air which has been centrifugally cleaned of water and dust through the lift fans.

The problem of directional control is, perhaps, one of the most difficult that the hovercraft designer has to face, particularly where simplicity is one of the fundamental design aims.

Directional control and manoeuverability are considered to be principal requirements for the E.M. series of hovercraft for, in its special purpose and freighting roles, the vehicle will probably be called upon to operate in confined areas. The moderate speed requirements and overload capabilities of the E.M.1. and E.M.2. imply that a high thrust efficiency should be aimed for in the static condition and through the hump speed. In the E.M.2. the problem of manoeuverability and low speed thrust have been tackled collectively, using three basic parameters. Two ducted fans are used, spaced as far from the vehicle centre line as possible, equipped with fully variable pitch, they give positive forces in both forward and reverse directions as required and, by differential use, a powerful turning moment. Rudders in the slipstream of these ducted fans provide adequate control for normal forward operation.

Accurate low speed manoeuvring requires the provision of a side force and on E.M.2. this is supplied by "puff-ports" which use cushion air to provide a low velocity jet. By placing these well forward a useful turning moment can also be obtained. At cruise, operation of this control will prevent drift during turns and help to maintain correlation between craft heading and track.

Ducted fans provide a solution to the low speed thrust requirement. As Fig. (5) shows in comparison to other systems of air propulsion the ducted fan characteristic gives an improvement in thrust at the low speed end of the scale. Superimposed on the performance curve Fig.(6) is the combined thrust of the two ducted fan units installed in E.M.2. with a total H.P. input of 540. In these propulsion units we have departed from the policy of employing traditional techniques and available components. The advantages of the ducted fan far outweigh the design and development effort which they absorb. We have, however, adhered to the concept of robust simplicity in design of the units, as far as is practicable the functional components of the rotating assemblies have been separated to simplify calculation. A diagram, Fig. (7) shows the relationship between the rotor, its shaft and bearings, the stators, the supporting duct, and the rudder assembly. Axial movement of a central rod effects the pitch change on the six blades of the rotor.

Use of ducted fans provide many advantages apart from increasing the low speed thrust efficiency. By increasing the solidity ratio of the disc we are able to reduce blade tip speed significantly, the tip speed of free propeller has a predominant effect on noise emission. At cruise condition the tip speed of the E.M.2. propulsion fan is less than 500 ft/sec, a free propeller absorbing the same power would be 60% greater in diameter and would be operating at a blade tip speed of 700-800 ft/sec. The noise problem is further tackled by employing noise damping material in the enshrouding duct. Yet other advantages are derived from the use of the ducted fan, a low tip speed reduces blade erosion, a problem which has beset hovercraft operators. Taking account of freight loading, the conditions under which loading will occur and the standard of labour which may sometimes be used, the duct provides a high degree of protection to the propulsion fan.

In congested harbours, spray from hovercraft has presented a nuisance particularly to operators of recreational craft. The E.M.2. in normal operating condition, has a cushion pressure which is lower than other amphibious craft and our use of a "soft" skirt will further reduce spray. The soft skirt approach, determined from the study of flexible systems, reduces skirt drag and in conjunction with the improved static thrust of the propulsion system, permits satisfactory speeds to be obtained in a semi-boating mode. This term is descriptive of a hovercraft operating with its flexible skirts immersed in the water, creating an effective seal to diminish spray emission.

All design features were selected to provide a vehicle which would operate in rugged conditions, they also have an effect upon the design and production costs. By using established design principles to create a "state of the art" machine, Enfield Marine do not need to carry out fundamental research, having neither the staff complement nor the facilities for these pursuits. An intriguing parameter upon which to compare vehicles is their cost/unit weight. Based on normal operating weight, amphibious hovercraft first cost lies between £5 and £7 per lb (£11-£15.4/Kg.); marine craft weight in at £3/lb (£6.6/Kg.) and the semi-amphibious approximate to £3.5/lb (£7.7/Kg.). We confidently predict that the E.M.2. will be offered at a cost of £2.6 - £3.0/lb (£6.6/Kg.).

5. FUTURE PROGRAMME At present, effort is concentrated on the production of E.M.2. vehicles and the E.M.1. design. We are confident that the successful operation of E.M.2. will expand the market for amphibious hovercraft freighters. It is evident that commercial operators will require vehicles capable of a multiplicity of roles. To meet these requirements Enfield Marine are presenting basic craft which can be rapidly and inexpensively modified for specific operational duties.

The designs of E.M.1 and E.M.2. permit increases in length and beam so that other vehicle sizes may be contemplated using the existing jigs, tools and components.

The introduction of a family of freight hovercraft will possibly generate a market which cannot be met by the production facilities of our factories at Ryde. Since only the simplest of jigs are required to assemble the vehicles, production may be set up in user countries with components despatched from the U.K.

Although the Enfield programme is concerned with freight hovercrafts, it is possible to fit out the basic craft for passenger and vehicle ferry or for military operational duties. Figs. 8 and 9 give impressions of the E.M.1. and E.M.2. in other guises.

In conclusion, the Enfield intent is to produce "go anywhere, do anything" hovercraft, which will establish their place in the overall transport scene. Rugged simplicity, coupled with moderate cost, will ensure the profitability of the Enfield Marine hovercraft.

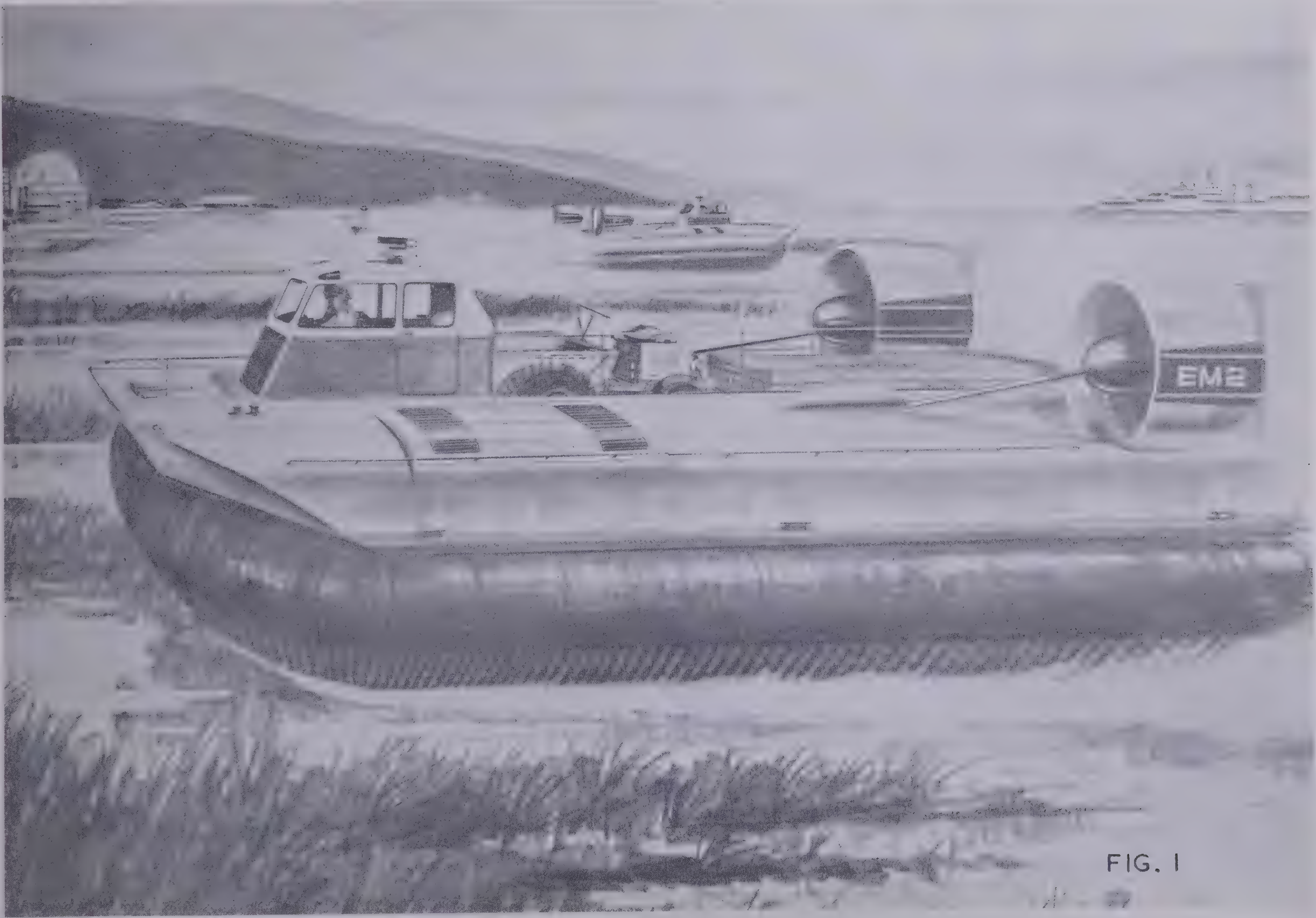


FIG. 1

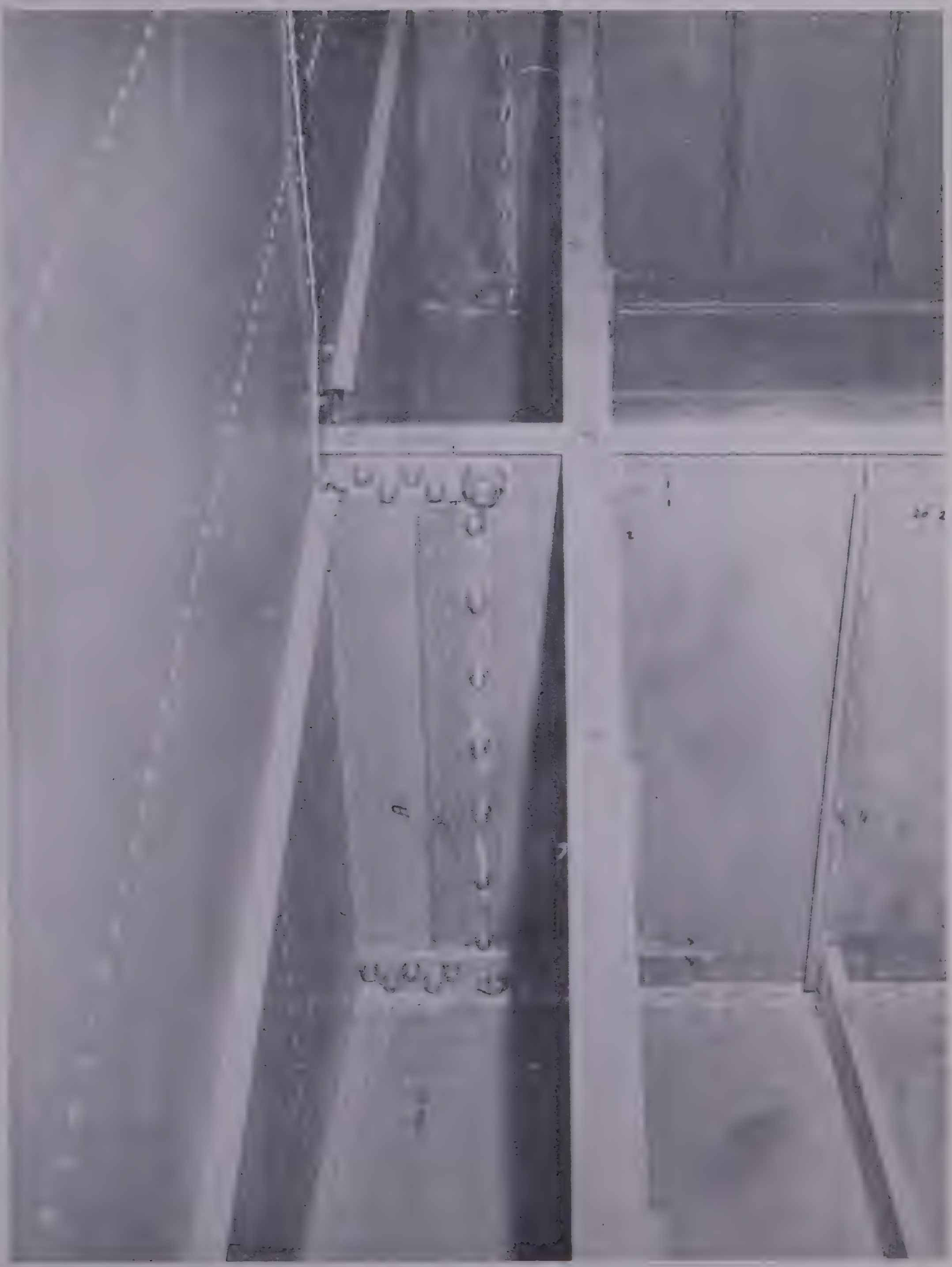
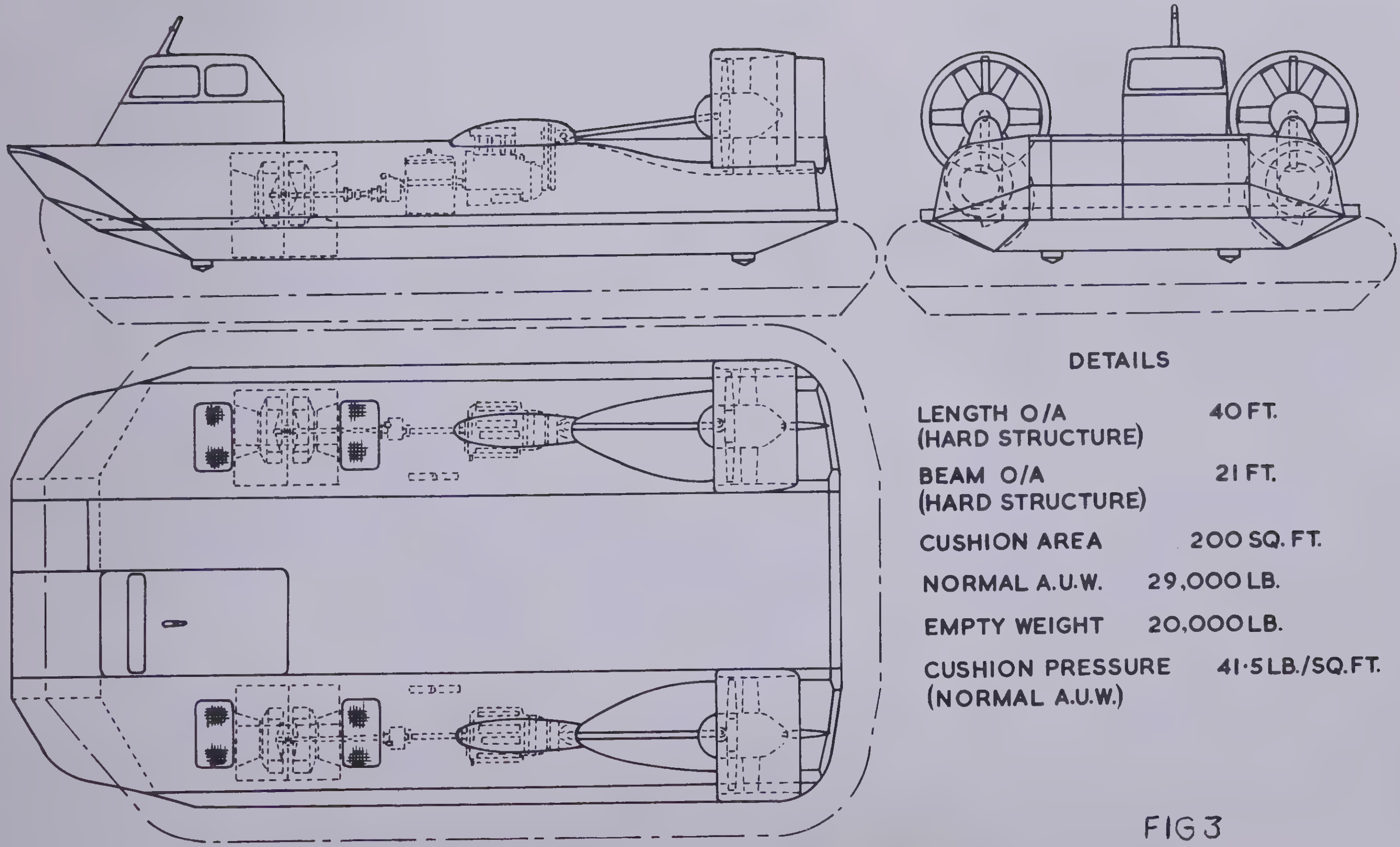


FIG. 2



DETAILS

LENGTH O/A (HARD STRUCTURE)	40 FT.
BEAM O/A (HARD STRUCTURE)	21 FT.
CUSHION AREA	200 SQ. FT.
NORMAL A.U.W.	29,000 LB.
EMPTY WEIGHT	20,000 LB.
CUSHION PRESSURE (NORMAL A.U.W.)	41·5 LB./SQ.FT.

FIG 3

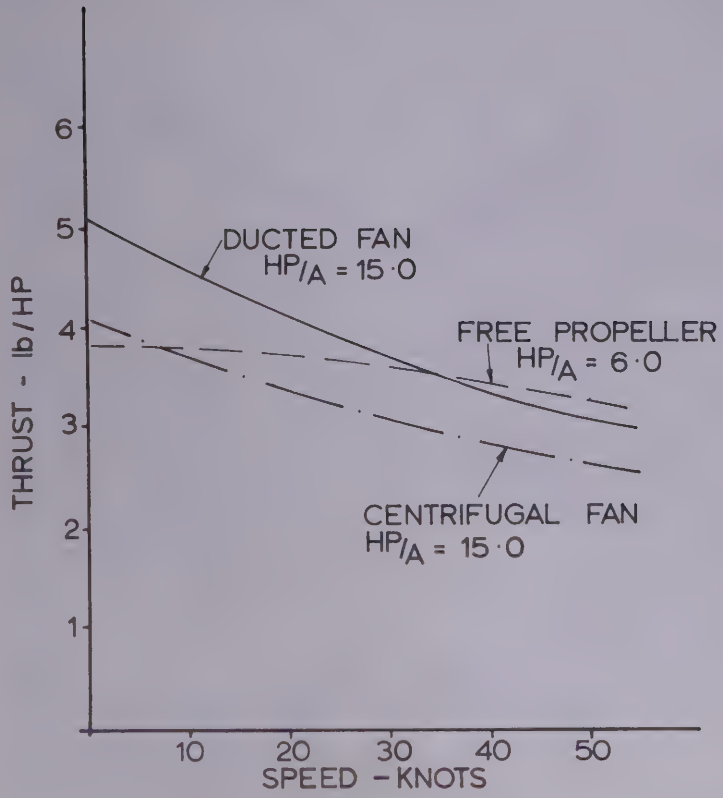

THRUST - lb/HP
6
5
4
3
2
1
10
20
30
40
50
SPEED - KNOTS
DUCTED FAN
HP/A = 15·0
FREE PROPELLER
HP/A = 6·0
CENTRIFUGAL FAN
HP/A = 15·0

FIG 5

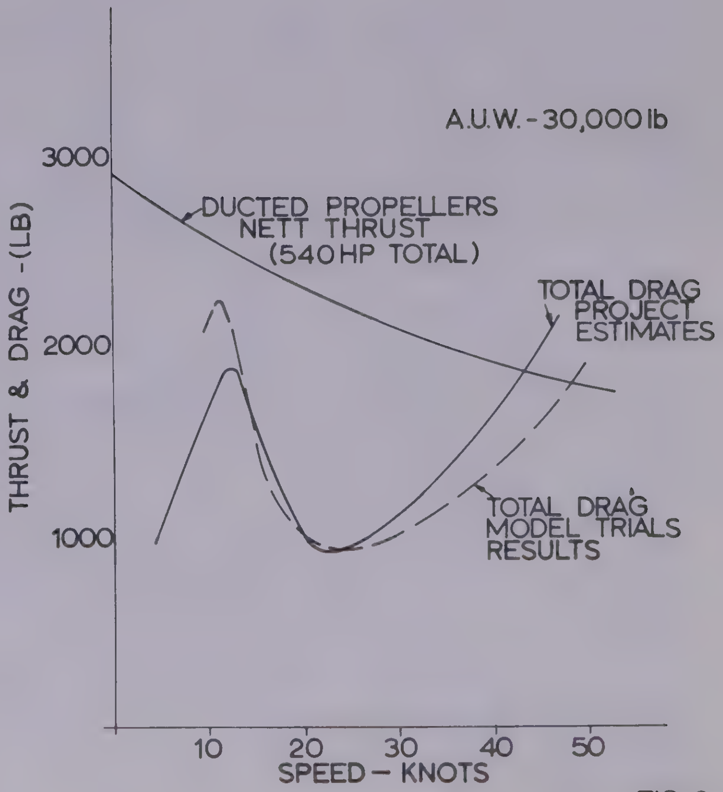

A.U.W. - 30,000 lb
THRUST & DRAG -(LB)
3000
2000
1000
10
20
30
40
50
SPEED - KNOTS
DUCTED PROPELLERS
NETT THRUST
(540 HP TOTAL)
TOTAL DRAG
PROJECT
ESTIMATES
TOTAL DRAG
MODEL TRIALS
RESULTS

FIG 6

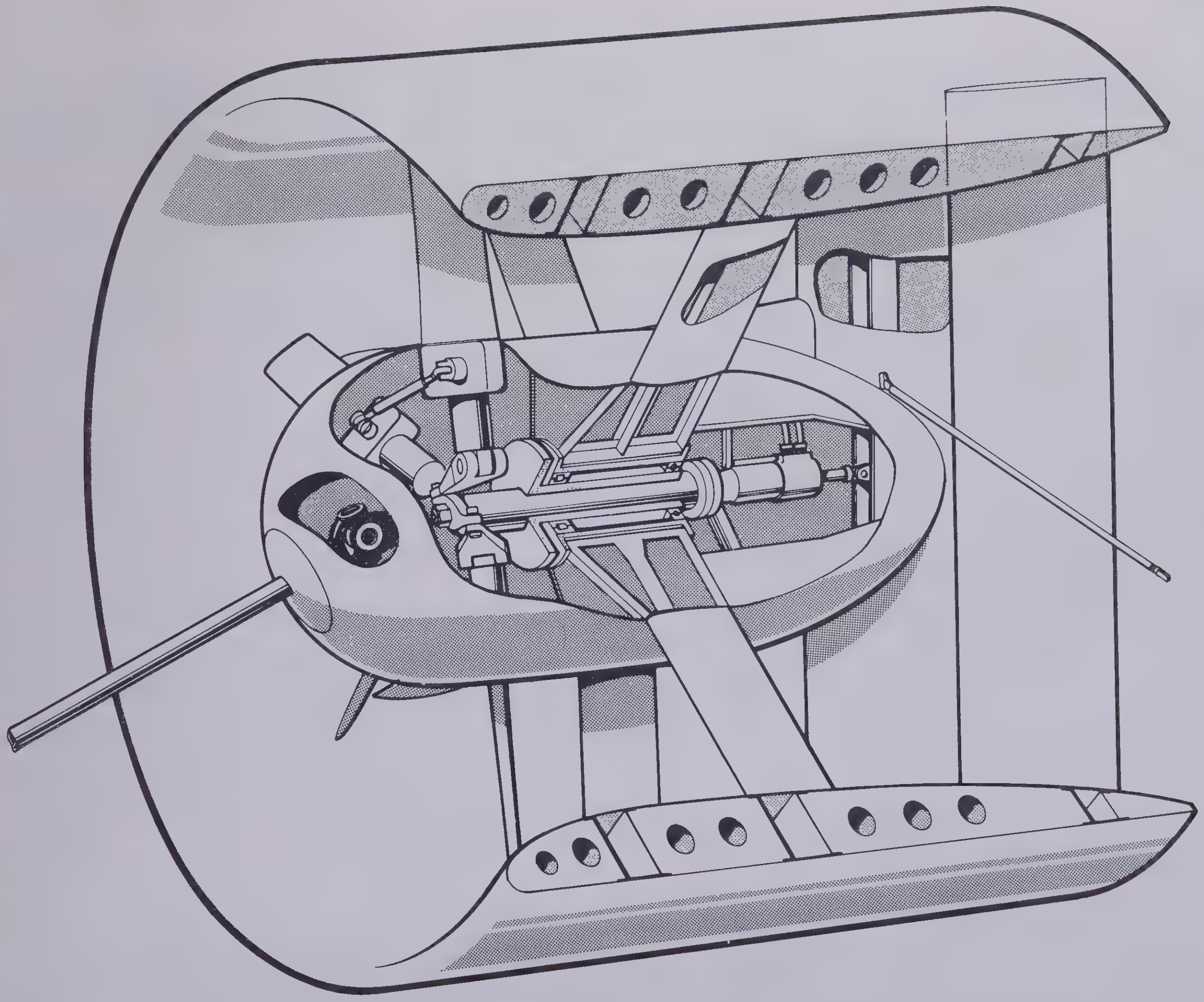


FIG. 7

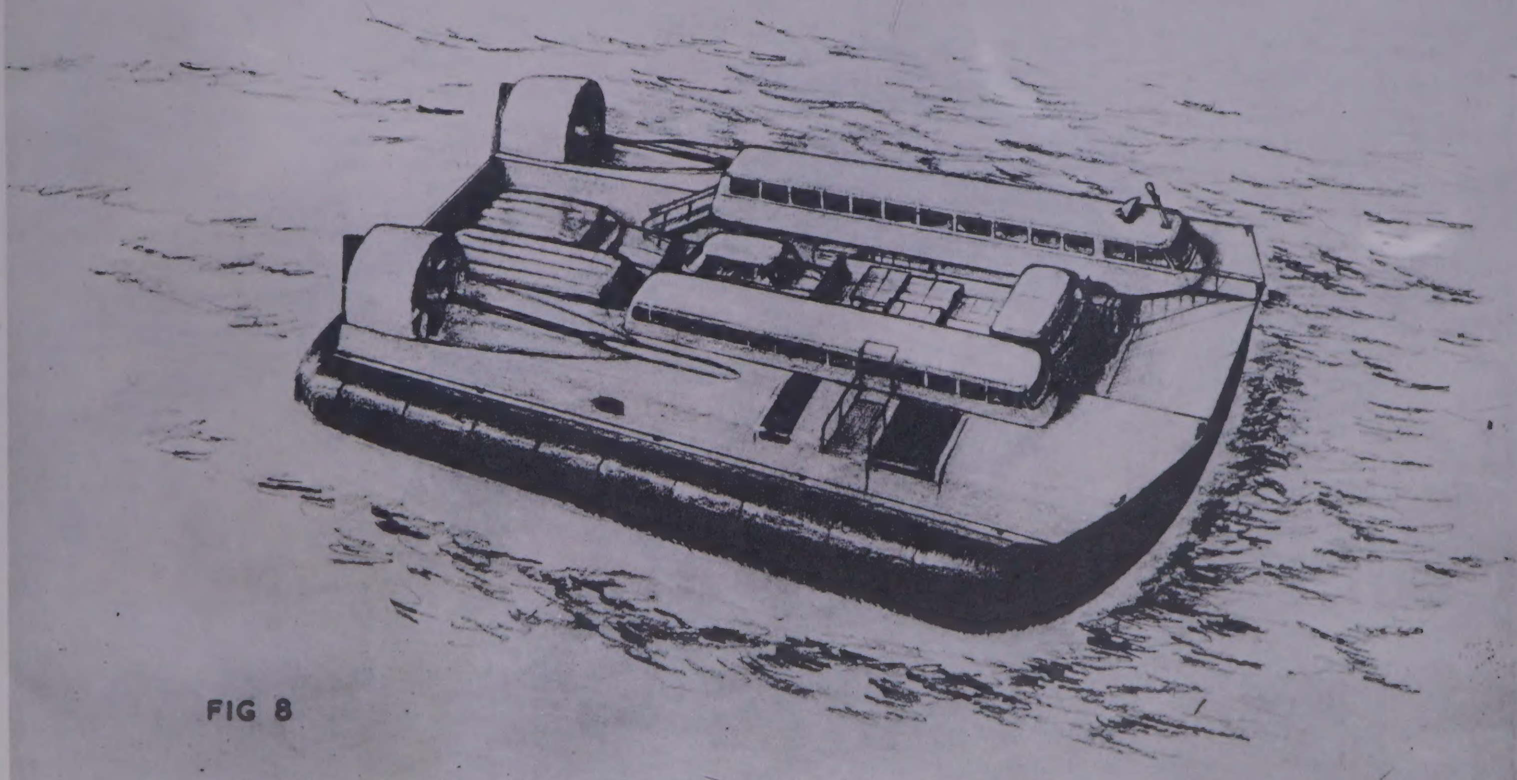


FIG 8

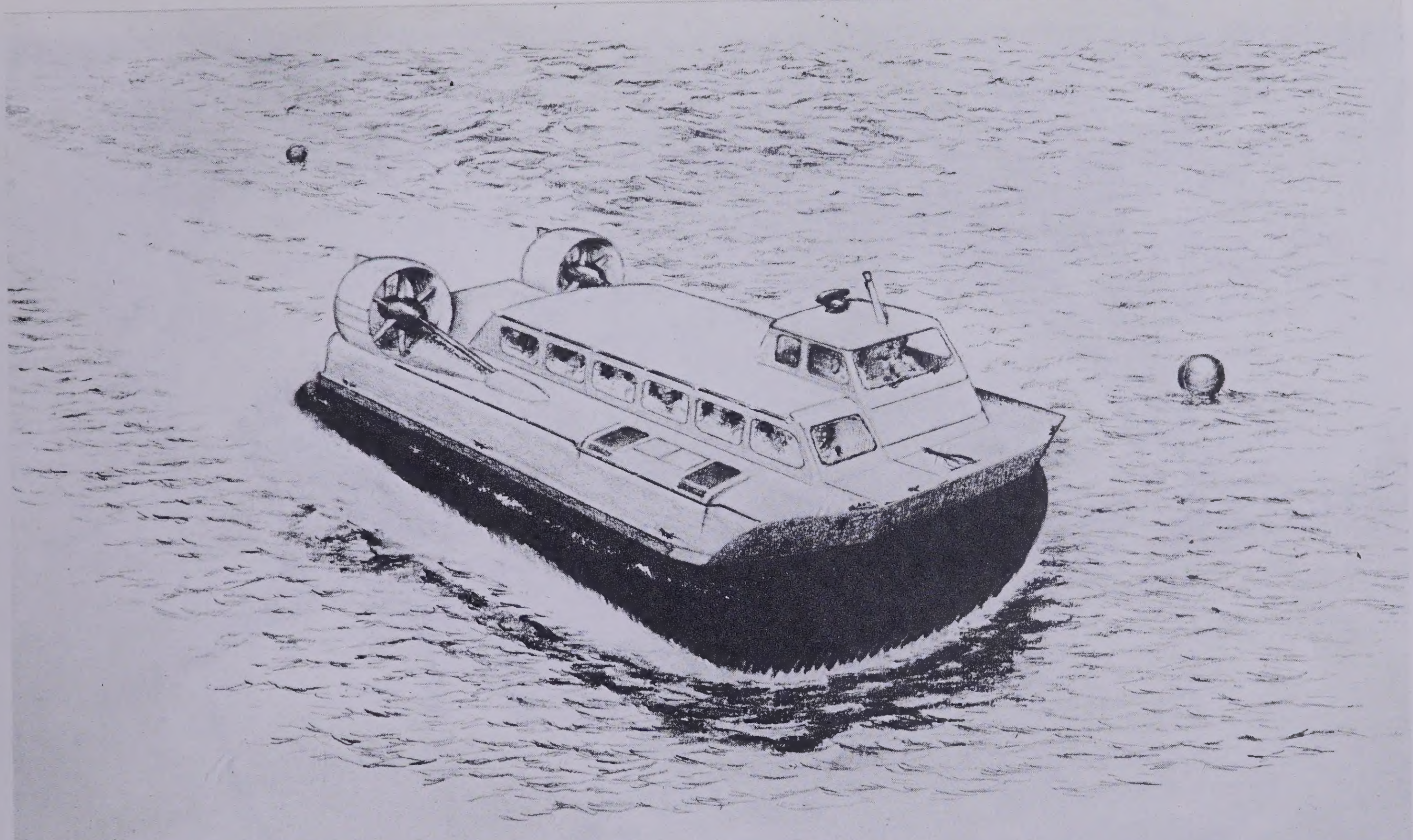


FIG 9

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